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STABLE CARBON AND NITROGEN ISOTOPE EVIDENCE FOR DIETARY VARIABILITY AT ANCIENT POMPEII, ITALY

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ABSTRACT

Stable carbon and nitrogen isotope results are presented for a sample of human and faunal bones and food remains excavated from Pompeii. The well-preserved organic remains provide a valuable resource to examine ancient lifeways associated with a Roman city during a distinct period of time associated with the eruption of Vesuvius in AD 79. Isotopic results indicate human diets that are consistent with the archaeological and documentary evidence for diverse dietary intake for all residents of Pompeii consisting of a range of cereals, fruits, vegetables, seafood, and meat from domestic and wild animals. Males had similar animal protein intakes to those of females, but they ingested significantly greater amounts of seafood than females. The great range of dietary variability among and between males and females indicated by the isotopic data suggests the existence of past dietary distinctions based on social role and/or social class. In comparison to other isotopic studies in the region, human diets at Pompeii are similar to those of Danish farmers and coastal Greek colonies in southern Italy (Metaponto) but included greater amounts of marine protein. Carbon isotope values for domestic animals indicate a C_3-based terrestrial diet, while nitrogen isotope values distinguish herbivores from omnivores and carnivores.

KEYWORDS: Stable Isotopes, Palaeodiet, Ancient Roman Diet, Pompeii, Italy.

1. INTRODUCTION

The excellent preservation of human remains and associated foodstuffs at Pompeii in relation to the sealing of archaeological deposits by volcanic ash with the catastrophic eruption of Vesuvius in AD 79 provides an unusual opportunity to employ stable isotope dietary reconstruction using human and faunal bone, bread remains and a range of domestic plant foods derived from closely associated deposits. As cremation was the dominant Roman mortuary practice at this time, the availability of large samples of human skeletal remains for bioarchaeological analysis is rare. This paper reports the results of stable carbon and nitrogen isotope analysis of a sample of human skeletons and associated food remains.

Due to the slow biochemical turnover rate of bone collagen, the stable carbon and nitrogen isotope composition of bone provides a record of long-term dietary intake. Amino acids liberated by the digestion of foods are incorporated into the proteins of body tissues including bone collagen. Stable carbon and nitrogen isotope analysis of human and animal bone excavated from archaeological sites has provided a valuable method for the determination of quantitative differences in past diets. Stable isotope methods allow the differentiation of relative quantities of general food categories such as marine foods vs. terrestrial foods and C_3 cereals (barley, wheat) vs. C_4 cereals (maize, tropical grasses) (Schwarcz and Schoeninger 1991; Schoeninger and Moore 1992; Pate 1994, 2008; Katzenberg 2000). In relation to Pompeii, stable carbon and nitrogen isotope analysis of bone collagen provides an independent means of assessing the relative proportions of seafoods vs. C_3-based agricultural products (wheat, domestic animals) in the diets of the urban population.

Furthermore, in contrast to conventional archaeological methods addressing dietary composition, bone collagen isotopic data for individual skeletons allow inferences about dietary differences and similarities between individual members of past social groups and communities (Sealy et al. 1995; Pate and Anson 2012; Pate and Owen 2014).

2. THE ANCIENT ROMAN DIET AT POMPEII

Ancient Roman literature, art and archaeological data (coprolites, carbonized food residues, floral and faunal remains) provide evidence for a diverse Mediterranean diet for both the upper and lower social classes at Pompeii (Meyer 1980; Ciarallo 2002; Faas 2005; MacKinnon 2004; Ellis 2011; Ciarallo and Giordano 2012; Moses 2012). Staple foods included bread, olives, cheese, a range of vegetables and fruits, fish and shellfish, poultry, wild game and wine. Wild game included boar, deer and waterfowl. Butcher's meat such as beef, lamb and pork was less common and was primarily associated with ritual sacrifices and elite dinner parties. Pork was the most common butcher's meat available in Pompeii. A popular salty fish sauce garum was employed to improve the palatability of various foods. Pompeii was known for the production and export of a high quality garum which was a core component of the ancient Roman cuisine.

A variety of vegetables and fruits were available to the residents of Pompeii. Vegetables included cabbage, broccoli, lettuce, endive, onions, leeks, asparagus, radishes, turnips, parsnips, carrots, beets and cucumbers. Tomatoes and capsicum peppers which are common in the modern Mediterranean diet were absent as they were not introduced from the New World until the 15th century. Common fruits included apples, pears, grapes, olives, figs, quinces and pomegranates. Seafood was more readily available than meat and included a range of fish (tuna, mullet, anchovies, eels), shellfish (oysters), and sea urchins. Bread was a major staple with numerous bakeries and associated grain mills present throughout Pompeii. Early bread was made from emmer, an ancient variety of wheat, while bread made from modern varieties of wheat became more popular during the early Christian era.

3. MATERIALS AND METHODS

Stable carbon and nitrogen isotope analyses involved human bone specimens and a range of archaeological faunal and floral samples recovered from the Pompeii site. The sample is derived from a large collection of excavated remains consisting of over 500 individuals and associated artefacts and ecofacts recovered from various regions of the city of Pompeii. Archaeological remains were recovered from the streets and from the rooms of houses and villas. The samples were obtained from the "storage place" (a partially excavated ancient public bath) at the Museum of Pompeii (Henneberg and Henneberg 1999, 2002, 2006).

The human sample consisted of 31 adults (12 males and 19 females). Domestic animals included a carnivore/omnivore (dog), an omnivore (pig) and herbivores (horse, sheep/goat, cattle), and domestic plants consisted of representative foodstuffs including barley, lentils, peas, and grapes. In addition, bones from a marine fish paste (*garum*), bread and a native grass (*erba*) were analysed.

In relation to human and faunal bone analyses, a 1 - 2 g cortical bone specimen was taken from each individual. Sample preparation involved ultrasonic

cleaning of whole bone specimens, demineralization, and sodium hydroxide treatment. Whole bone chunks were demineralized in dilute HCl according to the methods of Sealy (1986). Humic acids and other base-soluble contaminants were removed using a 0.125 M NaOH solution. Extracts were soaked and washed thoroughly following acid and base treatments in order to remove dissolved contaminants and the remaining organic component was oven dried at 35 C. Plant and food materials were oven dried at 40 C. All oven dried specimens were ground to fine powders using a Retsch mixer mill. Carbon and nitrogen concentrations of the ground powders were measured using an elemental analyzer, and stable carbon and nitrogen isotope values were determined by mass spectrometry using a Europa Scientific ANCA-SL system at at the CSIRO Land and Water laboratories in Adelaide, South Australia. Analytical precision was better than ± 0.1‰ for carbon and ± 0.3‰ for nitrogen.

Controls for post-mortem organic decomposition were implemented by excluding samples with: 1) Less than 5% collagen yield from the bone specimens; or 2) Less than 5% carbon yield from collagen; or 3) Less than 0.5% nitrogen yield from collagen (Ambrose 1990; Pate 1997, 1998; Schoeninger et al. 1989). Atomic C:N ratios in modern collagen were employed to determine the presence of acceptable collagen in archaeological extracts in relation to stable isotope analysis. These acceptable atomic C:N ratios were developed by extracting collagen from large samples of modern mammals and measuring their C:N ratios. Results include atomic C:N ranges of 2.9 – 3.6 for 172 mammals (DeNiro 1985) and 2.8 – 3.5 for 79 mammals (Ambrose 1990). Atomic C:N ratios were calculated according to the following equation: Atomic C:N = (14/12) X (Weight percent C:N).

The atomic C:N ratios for all of the Pompei bone collagen samples employed in this study were within the modern collagen range of 2.8 – 3.6. Four human bone collagen samples (2 male and 2 female) were excluded due to elevated atomic C:N ratios above the level of that of modern collagen (See Appendix A).

Human dietary composition was addressed employing standard bone collagen $\delta^{13}C$ values of -23‰ for a 100 percent C_3-based terrestrial diet, -13‰ for a 100 percent marine-based diet, and -7‰ for a 100 percent C_4-based terrestrial diet (van der Merwe et al. 1988, Pate and Schoeninger 1993). The validity of these values was confirmed using archaeological faunal controls derived from the Pompeii site. Because past atmospheric CO_2 was approximately 2‰ more positive than that in the modern atmosphere (Peng and Freyer 1986, Bada et al. 1990, Marino and McElroy 1991), a 2‰ correction factor was employed in relation to the use of modern faunal controls.

Bone collagen $\delta^{15}N$ values for archaeological sheep/goat, cattle, horse, pig, and dog were used to address trophic level, i.e. relative consumption of vegetable foods vs. animal protein, by the inhabitants of Pompeii. Bone collagen isotope values for modern sea lions from southern California ($\delta^{13}C$ = -13.1, $\delta^{15}N$ = 17.4, n = 2) and southern South Australia ($\delta^{13}C$ = -13.5 ± 0.3, $\delta^{15}N$ = 15.9 ± 0.4, n = 3) were used as a proxy for a 100% marine diet.

4. RESULTS

Bone collagen stable carbon and nitrogen isotope results for a range of domestic animals and foodstuffs recovered from the Pompeii archaeological site are presented in Table 1 as a reference sample for human palaeodietary inferences. Carbon isotopic values of –28.1 to –24.5‰ for domestic plants and local grasses indicate a C_3 photosynthetic pathway; whereas, nitrogen isotope values for plants are more variable with a range from 0.6 to 8.1‰. Carbon isotope values for domestic animals indicate a C_3-based terrestrial diet, while nitrogen isotope values provide evidence of trophic level differences for herbivores (cattle, sheep/goat, horse) vs. omnivores/carnivores (pig, dog).

Table I. Stable carbon and nitrogen isotope results for a range of domestic animals (bone collagen) and foodstuffs recovered from the Pompeii archaeological site, southwestern Italy.

Sample	n	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	Corrected $\delta^{13}C$ (‰)
Dog	1	8.5	-19.2	-21.2
Pig	1	7.0	-20.2	-22.2
Horse	1	4.2	-20.4	-22.4
Sheep/Goat	1	3.5	-21.0	-23.0
Cattle	1	3.4	-20.3	-22.3
Erba Grass	1	1.8	-26.6	-28.6
Grapes	1	8.1	-26.4	-28.4
Peas	1	2.0	-26.1	-28.1
Barley	1	0.8	-23.7	-25.7
Lentils	1	5.0	-23.0	-25.0
Bread	1	7.1	-21.7	-23.7
Garum (marine fish)	2	4.9	-12.2	-14.2

-2.0‰ correction to stable carbon isotope values in relation to changes in isotopic composition of atmosphere associated with burning of wood and fossil fuels

Because floral and faunal controls suggest a C_3-based terrestrial ecosystem, estimation of mean percentages of marine protein and terrestrial C_3 protein in the human diets was based on a simple linear model using stable carbon isotope values of

-23‰ for a 100 percent C_3-based terrestrial diet and -13‰ for a 100 percent marine-based diet (See Table 3).

Following the 2.0‰ correction related to changes in atmospheric $\delta^{13}C$, herbivore bone collagen $\delta^{13}C$ values range from –23.0 to –22.3‰, and there is a 1.1 – 1.8‰ difference between herbivores and dogs. In contrast, bone collagen $\delta^{15}N$ values show a 5‰ difference between cattle/sheep/goats and dogs. Stable carbon isotope values for *garum* are significantly more positive than those for the terrestrial mammals, reflecting the marine origin of this foodstuff. However, $\delta^{15}N$ values for *garum* do not differ from terrestrial fauna and fall between values for herbivores and omnivores. Thus $\delta^{15}N$ values suggest that *garum* was made using fish that fed at lower trophic levels.

Table 2. Human bone collagen stable carbon and nitrogen isotope means and ranges for Pompeii, southwestern Italy (prior to 2‰ correction for carbon).

Sample (n)	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
Total (27)	-19.0 ± 1.0	-20.1,- 15.8	9.8 ± 0.7	8.1, 10.6
Male (10)	-18.4 ± 1.4	-20.1, -15.8	9.7 ± 0.7	8.6, 10.6
Female (17)	-19.3 ± 0.4	-19.9, -18.4	9.9 ± 0.7	8.1, 10.6

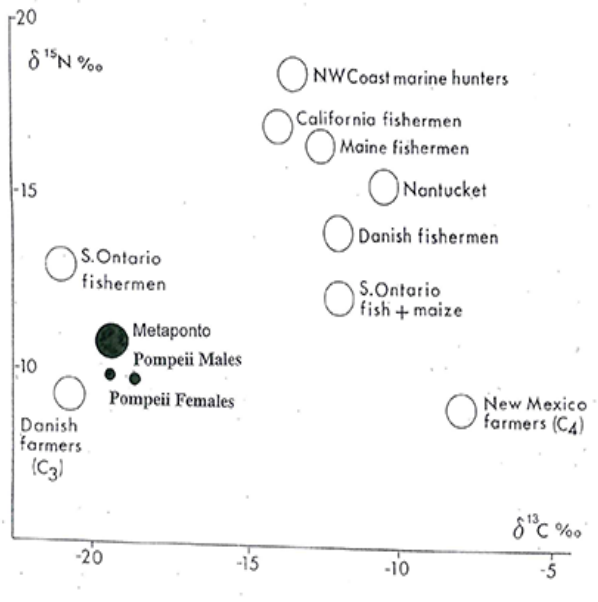

Figure 1. Mean bone collagen stable carbon and nitrogen isotopic values for human skeletal remains excavated from Pompeii and Metaponto, Italy in comparison to those for prehistoric human samples from other regions of the world (adapted from Little and Schoeninger 1995)

Human bone collagen stable isotope results for Pompeii are summarised in Table 2. Stable carbon and nitrogen isotope values indicate an omnivorous diet dominated by C_3 plants and meat from animals that fed on C_3 plants supplemented by various amounts of marine protein. In relation to previous palaeodietary studies, diets at Pompeii are similar to those of Danish farmers and coastal Greek colonies in southern Italy (Metaponto) but included greater amounts of marine protein (Figure 1). In addition, the lower mean $\delta^{15}N$ values at Pompeii in comparison to Metaponto suggest the consumption of marine foods from lower trophic levels, e.g. *garum*, or the consumption of lower quantities of animal protein by Pompeii inhabitants.

On average, Pompeii males had similar animal protein intakes to those of females, but they ingested significantly greater amounts of seafood than females. Estimates of marine protein components in the diet range from approximately 9-52% in males and from 11-26% in females with means of 26% and 17%, respectively (Table 3). Thus, using these calculations, the average C_3-based plant and animal food component of the diet was 74% for males and 83% for females.

Table 3. Estimates of percentages of marine protein in the diets of the adult inhabitants of Pompeii based on bone collagen stable carbon isotope values.

Sample	n	Mean (%)	Range (%)
Total	27	20	9 - 52
Male	10	26	9 - 52
Female	17	17	11 - 26

All adults = -21.0‰ or (0.20 x -13) + (0.80 x -23)
Adult males = -20.4‰ or (0.26 x -13) + (0.74 x -23)
Adult females = -21.3‰ or (0.17 x -13) + (0.83 x -23)

The observed variability in individual stable isotope values in both the male and female samples indicates that there were significant dietary variations within and between each of these groups. The stable isotope and atomic C:N data for individual human bone collagen samples are presented in Appendix A.

5. DISCUSSION

Stable carbon isotope values for domestic herbivores at Pompeii are similar to those for herbivores excavated from the Mesolithic (9000 BP) and Bronze Age sites of Uzzo and Toppo Daguzzo in southern Italy (Francalacci 1988). Thus, the diets of wild and domestic herbivores from southern Italy reflect a predominantly C_3 plant diet throughout the Holocene, and human dietary reconstructions for this region should not be complicated by the presence of C_4 plants (cf. Tauber 1983, 1986). A Mesolithic fox from Uzzo has a similar bone collagen $\delta^{15}N$ value (8.2‰) to the Pompeii dog (8.5‰).

Although *garum* has a $\delta^{13}C$ composition indicative of marine proteins, its low $\delta^{15}N$ value indicates that it is derived from marine foods from the base of the food chain, e.g. shellfish and herbivorous fish.

Stable isotope palaeodietary reconstructions for the inhabitants of ancient Pompeii are consistent with the archaeological and documentary evidence for diverse diets consisting of a range of fruits and vegetables, grains, seafood, and meat from domesticated and wild animals. The stable isotope data supplement archaeological information by providing quantitative estimates for various general food categories.

In contrast to the ancient Greeks at Metaponto in southern Italy (Henneberg et al. 1995, 1999; Henneberg and Henneberg 2003), Pompeii residents consumed greater quantities of marine protein. On average, marine protein consumption at Metaponto was 17% with a range of 5-40% vs. 20% with a range of 9-52% at Pompeii. Stable carbon isotope values suggest that, on average, males at Pompeii consumed approximately 9% more seafood than did females, and there are significant differences between the ranges for males (9-52%) and females (11-26%). Furthermore, the composition of male diets varied to a greater extent than did female diets.

Although all residents of Pompeii appear to have had broad, diverse diets, the significant range of dietary variability observed among and between males and females in relation to the stable isotope evidence provides support for hierarchical social differentiation within the community and different roles for males and females within these various social classes. Additional stable isotope research will be required to refine and clarify proposed dietary differences related to social role and social status.

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Appendix A. Adult human bone collagen stable carbon and nitrogen isotope and C:N data for individual samples from Pompeii, southwestern Italy.

Sample No.	Sex	Atomic C:N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
P-11	Male	3.0	-20.1	9.3
P-2	Male	3.2	-19.4	10.2
P-10	Male	3.2	-19.4	9.5
P-12	Male	3.0	-19.2	9.3
P-65	Male	3.3	-18.9	10.4
P-25	Male	3.3	-18.7	10.6
P-126	Male	3.3	-18.7	10.4
P-6	Male	3.4	-18.1	9.9
P-1	Male	3.2	-16.1	8.6
P-8	Male	3.2	-15.8	9.1
P-24	Female	3.3	-19.9	10.6
P-28	Female	3.0	-19.7	9.8
P-16	Female	3.2	-19.7	9.6
P-18	Female	3.0	-19.6	10.1
P-23	Female	3.2	-19.5	10.2
P-21	Female	3.2	-19.5	10.1
P-29	Female	3.2	-19.5	9.8
P-22	Female	3.2	-19.4	9.8
P-117	Female	3.2	-19.4	9.6
P-17	Female	3.2	-19.3	10.6
P-101	Female	3.0	-19.3	10.2
P-26	Female	3.5	-19.3	8.1
P-27	Female	3.3	-19.2	10.4
P-61b	Female	3.2	-19.1	10.3
P-15	Female	3.2	-18.9	8.2
P-19	Female	3.4	-18.5	10.4
P-3	Female	3.3	-18.4	9.9
Adult human bone collagen samples excluded due to elevated atomic C:N ratios				
P-4	Female	4.1	-17.6	5.9
P-9	Female	3.8	-16.6	5.9
P-7	Male	4.2	-15.7	8.8
P-61a	Male	4.0	-14.4	9.1